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THE PARALLAXES OF BRIGHT AND DARK DIFFUSE NEBULÆ

By Knut Lundmark

Sir William Herschel concluded from his observations that the nebulæ could be divided into two classes, the unresolved or partially resolved agglomerations of stars (spirals and clusters) and the real nebulæ (nebulous stars, irregular nebulosities and planetaries). The close connection between stars and nebulosities was noted by him, and he speaks about "the growth of stars by the gradual access of nebulous matter." He also recognized that the bright diffuse nebulosities very frequently are accompanied by vacancies among the surrounding strata of stars.

It is well known that astronomical photography has given the most wonderful results about the nebulæ. In numerous papers and in the great volume, *Milky Way and Comets,* Barnard has given the discoveries and results from his extensive studies of the distribution of nebular matter in our universe. Important results along the same line have also been reached by Roberts, Keeler, Wolf, Curtis, Pease, Hubble, and others. Raynard's and Barnard's idea seems now to be generally accepted, that the starless regions and "rifts" in the Milky Way are not real vacancies among the stars, but dark nebulous matter or obscuring masses in space which cut out the light from the nebulous or stellar regions behind them. The existence of what are best termed *dark nebulæ* seems to be definitely proved by Barnard, but he has also pointed out that some dark markings in the sky doubtless are only vacancies in the distribution of stars.

Wolf has been inclined to maintain this latter explanation for a number of dark markings where, at the end of the dark rift, a bright nebula is situated. He thinks that the nebula is moving in the direction of the rift through the Milky Way star clouds and by some process—using Herschel's word—is wasting the stars. Courvoisier tried to explain the formation of the star "holes" by the principles of hydrodynamics. He compared the motion of the bright nebula with the motion of a vortex in streaming water and found some analogies between the star hole and the slack water. From his inspection of photographs he found the very interesting fact that the direction of the dark rifts is in general parallel to the Milky Way and that they seem to converge towards a point in the constellation *Cygnus*. Wolf has shown that the directions for four dark rifts in the Milky Way accompanying bright nebulæ will converge very closely at $\alpha = 23^h.5$ and $\delta = +56°$. It may be of interest to note, without attempting any explanation, that the most probable value for the direction of the Sun's motion relative to the spiral nebulæ is found by the writer to be $\alpha = 23^h.0$, $\delta = +61°$, and relative to the globular clusters $\alpha = 2^h.3$, $\delta = +74°$.

The bright and dark nebulæ seem in most cases to be connected with the star clouds in the Milky Way, and some connection seems to exist between the distribution of nebular matter and the distribution of novæ and planetaries. Furthermore, we frequently see in the spirals evidences of the presence of nebular matter and formations analogous to the dark nebulæ in the Milky Way, but only of smaller dimensions.

Any information we can get about the distances of the bright and dark nebulæ would thus be of value in estimating the dimensions of the stellar system. Direct measures, of course, we cannot make, but there exist some indirect methods which, especially when better and more extensive observational material has been collected, will give us a fair conception of the distribution in space of these bodies. Most of the methods sketched here will hold as good for one theory of the real nature of the dark markings as for the other.

a. It is known that the stars involved in nebulosity generally belong to Class B or Class A. The close connection between the early type stars and the diffuse nebulæ is beautifully shown by the fact that Dr. Campbell from the circumstance that a star was involved in nebulosity but entered in the catalog as a G star could predict that the classification was wrong. Now, the B and A stars have a rather constant absolute magnitude, and assuming this quantity known from direct and hypothetical determinations of the parallaxes it will be possible even for a single B or A star to get a fair idea of the parallax if the apparent magnitude is known. This method is used by Charlier and his pupils for getting parallaxes of the earlier classes of stars. As we have in many cases a group of B and A stars involved in a bright nebula, we get a good value of the parallax by this method. Supposing then that the accompanying dark markings really are connected with the bright nebula, we also get parallaxes for a number of those objects.

b and c. Knowledge of proper motions and radial velocities will give much information about the parallaxes of stars connected with nebulosity. According to the discovery by Wolf and Courvoisier already quoted, it seems justified to assume as a working hypothesis that the real motions will take place in directions parallel to the Milky Way. As the motions are small, another justifiable assumption is that the v components of the proper motions are due entirely to a reflection of the solar motion.

d. In his plan of "Selected Areas," Kapteyn gives an ingenious method which, assuming that the dark markings are due to dark matter, will give their parallaxes. For the stars projected against dark nebula and the surrounding stars, if the latter are also more distant, will have different parallactic motions and the systematic measurement of plates of such regions will therefore provide the data needed for parallax determinations. At present we do not have material good enough to use that method.

e. Determinations of the distribution of stars according to different magnitudes will give a good estimate of the distance for many dark nebulæ. If we count the stars in a region where such an object is situated we generally find that the brighter stars seem to be uniformly distributed all over the area. But at a certain magnitude the influence of the dark marking becomes evident because stars of this magnitude and fainter ones are lacking or are very few. Assuming that the mean parallax is known for stars of different magnitudes, we thus get an idea of the distance to the dark object without any assumption as to its real nature. Knowledge of the spectral classes or color indices for stars dealt with would of course enable us to refine the scheme. The method was applied by Buch-Andersen to the *North America Nebula,* and he obtained in this way a parallax value of $0''.007$, in agreement with determinations given in this paper. Work along this line has been started in Upsala by Mr. Asklöf and the writer. A few preliminary results are communicated in this paper.

Of course, the area occupied by the dark nebula must have such an extension that the number of the stars can be treated statistically. As a rule dark markings smaller than one square degree should not be investigated by this method.

f. We have the well-known fundamental equation in stellar statistics:

$$A(m) = 4\pi \int_0^\infty D(r)\, \phi\, (h\, r^2)\, r^4\, d\, r$$

where $A(m)$ is the number of stars brighter than magnitude m, $D(r)$ is the number of stars per unit volume at the distance r, h denotes the apparent brightness, and $\phi\ (hr^2)$ the frequency of absolute brightness. Starting from this, Pannekoek derives a relation which will give the distance r to a screen absorbing ϵ magnitudes, if we observe the actual star distribution $A^1(m)$ for the area covered by the screen and the distribution $A(m)$ in the surroundings. Theoretically it will be possible to determine both r and ϵ and thus also to derive a knowledge of the amount of the absorption in dark nebulæ. In general it will be difficult to apply this method because the observed range in magnitudes will be too small to separate the two unknowns. For the extended dark nebulæ in *Taurus* this method was applied by Pannekoek with good success, as the resulting parallax, 0″.007, will closely agree with the parallax value derived from Trümpler's extensive investigations for the *Pleiades,* which cluster evidently is connected with the said dark nebulæ.

g. Double stars involved in nebulosity which show orbital motion give, by using Hertzsprung's or Russell's methods, hypothetical parallaxes.

h. Of course, the nebulous stars will be a very fruitful field for parallax *measures* of different kinds, and some results are already available.

i. The fact that some stars undoubtedly seem to be projected against dark nebular matter will also give a means for determining a minimum value of the distances. Here, for more accurate results, knowledge of the spectral types or color indices for the stars is needed. With the aid of proper motions it may, according to (d), be possible to select actual cases of projection.

j. It is evident that in some cases the nebulæ condensing about stars or extending from certain stars only show the reflected light from the stars and do not show any light of their own. Now, in a few cases changes in the nebula are observed which evidently, according to Hubble's discoveries, are due to the reflection of the light. By comparing the light velocity with the observed changes, a maximum value for the parallax can be obtained.

k. A few bright nebulæ, e. g., *the Network Nebula* in *Cygnus* and the *Crab Nebula* in *Taurus,* seem not to have any stars involved, neither is the distribution of stars within, and in the regions surrounding the nebulæ affected in any way by these objects. For the present it looks almost impossible to find any method which will enable us to get the parallaxes for such exceptional cases. As discovered by Lampland and Duncan, the latter nebula shows considerable motion in a sense of a general expansion. Measures of the radial velocity at different epochs could perhaps give the changes in the nebula in the direction of the line of sight. Supposing the expansion to be equal in different directions, comparison of the rate of extension in angular and linear measure will give the parallax.

In the table some preliminary parallax values obtained by different methods are collected. The material is obtained principally from the large collection of negatives at the Lick Observatory, from the writer's own plates, and from Wolf-Palisa charts and other published collections of astronomical photographs. The spectra are obtained from published and unpublished parts of the *Henry Draper Catalogue* and from the paper by Seares and Hubble, *The Color of the Nebulous Stars.* Results obtained by Lindblad and the writer on the color index and spectral types of nebulæ and partially published in the *Astrophysical Journal* (**46** and **50**) have also been used.

The values of the absolute magnitude of the early type stars have been obtained by a study of the measured parallaxes and from the known moving clusters and by using values derived by Charlier and others from proper motions and radial velocities.

I am deeply indebted to Dr. Campbell for putting at my disposal the Lick negatives, to Dr. Shapley for communicating spectral types from unpublished parts of the *Henry Draper Catalogue,* to Professor Barnard for sending reprints of his Milky Way photographs, and to Dr. Aitken for furnishing data for a double star.

TABLE I.

NAME	α	δ	CHARACTER	π	METHOD
N. G. C. 281	$0^h47.4^m$	+ 56° 3′	Nebulous star	0″.0009	a
N. G. C. I. 59 . . .	0 50.7	+ 60 11	Diffuse nebulosity	0.010	a
				0.008	c
				0.022	h
				0.013	
N. G. C. II. 1805 .	2 24.5	+ 61 3	Cluster + diff. neb.	0.0007	a
Nova Persei	3 24.4	+ 43 34	Nova + nebulosity	0.005	c
				0.011	h
				0.009	j
				0.005	k
				0.008	
o *Persei*	3 38.0	+ 31 58	Star in neb. region	0.006	a
				0.006	c
				0.006	
Pleiades	3 41.	+ 24	Cluster + neb.	0.010	—
+ 25°.624	3 44.3	+ 25 17	Nebulous star	0.014	a
				0.028	c
				0.018	
	3^h20^m-4^h30^m;	26°-30°	Dark nebulosities	0.007	f
				0.009	e
				0.007	
N. G. C. 1514 . . .	4^h 2.9^m	+ 30°30′	Star in nebulosity	0.002	a
				0.001	c
				0.002	
N. G. C. I. 405 . .	5 9.7	+ 34 12	Star connected with nebulosity	0.0020	a
				0.0008	c
				0.0014	
N. G. C. I. 410 . .	5 16.	+ 33 23	Cluster + nebulosity + dark lane	0.0020	a
N. G. C. I. 417 . .	5 20.	+ 34 21	Cluster + nebulosity	0.0010	a
N. G. C. 2070 . . .	5 39.5	− 69 5	Nebulous star	0.0001	a
Orion region . . .			Bright nebulous stars	0.007	a
				0.006	b
				0.006	c
				0.006	
Orion nebula . . .	5 30.	− 5 27	Cluster + bright nebula + vacant region	0.004	a
				0.006	b
				0.002	c
				0.002	c
				0.004	g
				0.002	h
				0.0036	

Orion region					Nebulous stars	0.0009	a
	6	3.2	— 6	13	Nebulous stars	0.0009	a
N. G. C. 2175	6	3.7	+ 20	31	Nebulous star	0.0009	a
N. G. C. I. 446	6	25.3	+ 10	32	Nebulous star	0.0010	a
N. G. C. 2245	6	27.2	+ 10	14	Cluster + diffuse nebula	0.0040	a
N. G. C. 2237	6	27.	+ 5	0	Cluster + bright	0.0020	a
					+ dark nebula	0.0025	c
						0.0022	
N. G. C. 2261	6	33.7	+ 8	49	Star and variable	—0.011	h
					nebula	+0.0004	j
S *Monocerotis*	6	35.5	+ 6	59	Cluster + bright	0.0015	a
					+ dark nebula	0.0007	b
						0.0013	c
						0.0016	g
						—0.0003	h
						0.0010	
—12°.1771	7	0.6	— 12	11	Nebulous star	0.003	a
η Carinæ	10	41.2	— 59	9	Nova + nebulous	0.0010	a
					stars + bright and	0.0022	c
					dark nebulæ	0.0016	d
						0.0015	
Anonyma	11	9.2	+ 55	31	Nebulous star	0.0001	a
N. G. C. 5189	13	26.4	— 65	28	Stars and nebulosity	0.0030	a
Nova Circini	14	40.5	— 59	35	Nova in dark lane	0.001	e
	16	14.	— 19	59	Nebulous star +	0.005	a
					dark nebula	0.006	c
						0.006	h
						0.006	
	16	19.	— 23	13	Nebulous stars near	0.004	a
					ρ Ophiuchi	0.013	c
						0.007	
ρ Ophiuchi 6 *Scorpii* 22 *Scorpii*	16	20.	— 25		Nebulous stars +	0.006	a
					dark nebula	0.006	c
						0.007	
	16	20.	— 25		Bright stars in nebulous region	0.008	a
						0.008	h
						0.008	
Trifid nebula	17	55.7	— 23	2	Bright and dark neb.	0.006	a
	17	55.1	— 27	50	Black spot in star cloud	0.0008	i
Messier 8	17	58.4	— 24	20	Cluster + nebula	0.0011	a
						0.0037	c
						0.0020	
	18	0.	— 23	57	Nebulous star	0.0003	a
	18	4.	— 23	56	Group of neb. stars	0.0017	a
	18	11.	— 19	43	Group of neb. stars in dark space	0.0010	a

	18 9.	— 18 15	Dark nebula	0.002	i
Messier 17	18 15.	— 16 14	Nebula and stars	0.0009	a
— 10°.4713	18 26.	— 10 52	Nebulous stars in dark nebula	0.005	a
				0.010	c
				0.007	
	18 55.1	— 37 6	Nebulous region	0.008	a
	19 14.	+ 7 32	Dark nebula	0.005	i
	19 35.	+ 10 20	Dark nebula	0.0025	e
Barnard No. 144 .	19 54.	+ 34 30	Vacant region	0.0002	e
N. G. C. 7000 . . .	20 50.	+ 44 0	Bright and dark nebulæ	0.0040	a
				0.0058	e
				0.0045	c
				0.0053	
N. G. C. 7023 . . .	21 0.5	+ 67 46	Bright and dark nebula	0.007	a
				0.003	c
				0.005	
+ 67°.1332	21 35.0	+ 67 44	Nebulous star	0.003	a
				0.015	c
+ 56°.2617	21 35.9	+ 57 2	Cluster + bright + dark nebulæ	0.0010	a
				0.0008	c
				0.0009	
N. G. C. 7635 . . .	23 16.5	+ 60 39	Nebulous star	0.0008	a

REMARKS

o Persei. The region is very extended and also includes the *Pleiades.* The parallax for the nebulous region R. A. 3^h20^m-4^h30^m and Decl. 26°-30° is derived from extensive star counts by Pannekoek.

Pleiades. Parallax value from Trümpler's researches.

N. G. C. 1514. The suspected spiral structure does not exist. The spectrum seems to contain N lines.

N. G. C. I. 405. The "flaming star" discovered by Wolf. Most beautiful example of star connected with nebulosity. The nebula is like a gigantic prominence thrown off from the star. The objects N. G. C. I. 405, 410, and 417 seem to be at about the same distance from us.

N. G. C. 2070. A star situated in the Large Magellanic cloud. Parallax uncertain, but is in harmony with other evidences for the distance to this object.

N. G. C. 2261. Hubble's variable nebula. The measured parallax-value is obtained by van Maanen.

$11^h9.2^m$, + 55°31′. Found to have a color index corresponding to early B stars. In *Ap. Jour.*, **50**, 1918, a parallax of the same size was suggested. Spectrum not known.

19^h14^m + 7°32′. Parallax derived from star counts by Pannekoek.

19^h54^m + 34°30 The parallax for this singular region is derived from extensive star counts by the writer and Mr. Asklöf. The value is of a provisional character, as the results are not yet worked out in detail.

N. G. C. 7000 is the *North America Nebula.* Parallax according to method *e* is obtained from Buch-Andersen's paper by using more modern values for the mean parallaxes for stars of different magnitudes.

As a general result it should perhaps be pointed out that the nebular objects investigated seem not be in our immediate neighborhood, but at the same time not at considerable distances. It is evident that some of the objects form part of the Milky Way structure and that the distances to the objects in *Monoceros, Orion* and *Cygnus* also will give some idea of the distances to this part of the Milky Way.

Some of the nebulosities are very extended. According to Henreautau the nebulosity connected with the *North America Nebula* is extended over an area of 10 square degrees, and we find thus that its area will fill 35 square parsecs. The nebula itself has a length of 6.8 parsecs.

Another result is that the Wolf-Rayet stars connected with the nebulosities must have a very high absolute magnitude. A value of — 4 is suggested from the present investigation. Now, Hertzsprung found from parallactic motions in the mean — 2.8 and Gyllenberg — 1.8. Both assume a value of 20 km. for the Sun's motion relative to the system of Wolf-Rayet stars, but an inspection of known radial velocities suggests a value of about 40-50 km. for this motion, which would bring the mean absolute magnitude in better agreement with the value of — 4. Now, the directly measured parallaxes of van Maanen give a considerably lower absolute magnitude, and it may be possible that among Wolf-Rayet's stars we may have to recognize a division into giants and dwarfs. We may recall that the nuclei of planetaries, which also are Wolf-Rayet stars, according to van Maanan's parallaxes, are of the absolute magnitude + 8.4.

From the known linear dimensions of the dark nebulæ in our stellar system we could get some estimate of the parallaxes for spirals by assuming the linear dimensions of the dark markings in spirals in the mean to be the same. From this assumption we get the following parallaxes for a few well-known spirals:

OBJECT	π
N. G. C. 224	0″.000050
598	0 .000030
2903	0 .000003
3031	0 .000015
5194	0 .000005
6946	0 .000004

From Curtis's work it is evident that the dark bands or lanes frequently observed in spirals seen edgewise must contain dark matter. An inspection of the Crossley photographs shows that sometimes stars are projected against these dark lanes. It has previously been shown that the open spirals seem not to be affected by the general star distribution and thus very probably are situated behind the space occupied by the stars to 16 or 17 magnitude. The same conclusion is suggested from star counts made on plates showing spindle nebulæ. We find thus for N. G. C. 891, situated in a comparatively star rich region, that the star density in the area occupied by the nebula is 17. The mean star density in the surroundings is, for an equal area, 18. It is also evident that just as many Milky Way stars are projected on the dark lane as we should expect on the assumption of a uniform distribution of the stars on the plate. N. G. C. 4594 shows four stars projected on the nebula and one on the dark space, in agreement with the mean star density in this region for corresponding areas. Thus it seems justifiable to conclude that these nebulæ are farther away than the faintest stars on the plates. In the following table we give the maximum values for the parallaxes derived in this way. As spectra of the projected stars are unknown we compute the mean parallax from the formula,

$$\log \pi m = 8.943 - 0.142m$$

where πm denotes the parallax for the stars of magnitude m.

OBJECT	PARALLAX SMALLER THAN
N. G. C. 891	0″.00015
3034	0 .00018
3623	0 .00025
3628	0 .00025
4013	0 .00025
4565	0 .00020
4594	0 .00025
5195	0 .00013
5866	0 .00018
7814	0 .00013